SOIL RESOURCES

Introduction

This report summarizes existing environment and anticipated effects of activities proposed in the Mud Creek project relative to soil resources. This analysis includes a review of the relevant regulatory frameworks, issues identified during public involvement, and a summary of soil assessment methods. The focus of this analysis is connected to mechanical harvest, road construction and prescribed burning activities and the potential effects of these actions on the soil resources indicators: Soil Quality and Soil Organic Matter.

Project scoping identified concerns regarding soil disturbance on terraces and general soil compaction in the project area as well as concerns about weed infestations following vegetation treatments; these concerns are further documented in the Affected Environment and Environmental Consequences sections of this report.

The Bitterroot National Forest has developed a Soil Risk Evaluation Framework (SREF) to aide in the adaptive management strategy within the condition-based approach. The SREF is further explained in the methods section of this report. Project activities such as vegetation harvest, prescribed burning, and temporary road construction will be analyzed in terms of soil productivity using the SREF process. This will provide for a spatial representation of high-risk areas prior to implementation and allows for site-specific resource protection measures in less resilient areas.

The implementation of design features documented in EA, Appendix A and site-specific resource protection measures reviewed during the SREF pre-implementation review will ensure that soil quality is maintained within the project area in accordance with all relevant laws and policies. These design features have been monitored for resource management effectiveness through the Bitterroot's Forest Plan monitoring program (PF-SOILS-006). The project activities analyzed below will maintain quality and soil organic matter in compliance with the Bitterroot Forest Plan, the National Forest Management Act, and Region 1 Soil Quality Standards as well as other state and federal policies. A project soil scientist will remain engaged in project implementation.

Analysis Framework: Statute, Regulation, and Policy

The Bitterroot National Forest Land and Resource Management Plan and Forest Service Manual 2500 and 2550, provide direction for the management of soils within activity areas. This direction can be found in the following documents.

The National Forest Management Act

The Bitterroot Forest Plan (USDA Forest Service 1987)

Forest Service Manual (FSM 2550)

FSM 2500 – R-1 Supplement R1 2500-99-1 (PF-SOILS-002)

Montana State Guidelines for Best Management Practices (BMPs) (PF-SOILS-004)

Soil and Water Conservation Practices (SWCPs) Handbook 2509.22 (PF-SOILS-004)

Executive Order 11990

Bitterroot Forest Land and Resource Management Plan

The Bitterroot National Forest Plan provides overall guidance for the management of lands of the BNF. It describes the desired conditions toward which the management of the land should be directed. The overarching goal of the Bitterroot Forest Plan is to maintain soil quality and manage for soil organic matter in order to provide for sustained land productivity for management objectives. The Soil and Water Conservation Practices

Handbook, Forest Service Manual (FSM) and recent National Core BMP direction are all incorporated as complementary information to the 1987 Bitterroot Forest Plan. They describe the BMPs that National Forests should use when implementing projects that could adversely affect soil and water resources. BMPs applicable to this project are identified in PF-SOILS-004 and in the Design Features (EA, Appendix A).

State and Local Law

The Montana State Guidelines for Best Management Practices apply to all activities on private, state or federal land and work in concert with the National Core BMP direction. Forest BMP monitoring includes evaluation of timber sale compliance with State BMP guidelines as well as the National BMP guidance and the Forest Plan. Compliance with Montana State BMPs is documented in the Aquatics Report.

Analysis Methods / Information Sources

The analysis methods and sources of information used to evaluate the existing condition and potential effects to soil resources include the following: Changes in soil quality (Detrimental Soil Disturbance (DSD)) and Changes in soil organic matter (Coarse Woody Debris (CWD)). The sources of information used in the description of these soil indicators prior to, during and after implementation include:

- Existing soils and landtype mapping within the analysis area further described in the Bitterroot National Forest Land System Inventory (NRCS soil survey).
- Soil risk category mapping and subsequent classification of the project area based upon the SREF framework (PF-SOILS-008).
- Field assessment of existing DSD soil conditions in proposed treatment units deemed high risk (SRC = E, F) and/or moderate risk (SRC = C, D) conducted by a professional journey level soil scientist.
- Field assessment of existing CWD soil conditions in proposed treatment units conducted by a professional journey level soil scientist.

Resource Indicators and Measures

Soil resource indicators are derived from the Bitterroot Forest Plan, NFMA, Region 1 Soil Quality Standards, and State and local regulatory frameworks. This analysis framework requires maintenance of soil quality, measured as detrimental soil disturbance and management of soil organic matter, measured as coarse woody debris. This report tiers to these indicators and their associated measures; Table S1 explains resource indicators and measures for assessing effects to the soil resources in the Mud Creek planning area.

Table S1. Resource indicators and measures for assessing effects

Resource Element	Resource Indicator	Measure (Quantify if possible)	Used to address: P/N, or key issue?	Source (LRMP S/G; law or policy, BMPs, etc.)?
Soils	Changes in soil quality	Detrimental soil disturbance in excess of 15% on a per area basis	Key Issue	National Forest Management Act, Forest Service Manual (FSM 2550), FS Region 1 Soil Quality Standards, and the Bitterroot Forest Plan
Soils	Changes in soil organic matter	Forest floor and coarse wood debris	No	Region 1 Soil Quality Standards and *Coarse Woody Debris Recommendations for the Bitterroot National Forest*

Resource Indicator: Soil Quality (DSD)

Forest Service Manual (FSM) 2550 defines soil quality as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation and ecosystem health." Soil quality is influenced by dynamic soil properties and can be influenced by management activities. In Region 1, Soil Quality Standards are used to identify measurable soil characteristics and set detrimental disturbance thresholds related to soil function for these characteristics. For example, soil compaction negatively impacts soil bulk density which results in reduced function of soil-water infiltration and root penetration abilities; therefore this measurable attribute (compaction) can be used as a proxy for the inverse of soil quality. Per FSM 2500-2014-1, detrimental soil disturbance (DSD) for individual soil physical properties are defined as:

- Compaction. Detrimental compaction is a 15 percent increase in natural bulk density. The cumulative effects of multiple site entries on compaction should also be considered since compacted soils often recover slowly.

- Rutting. Wheel ruts at least 2 inches deep in wet soils are detrimental.

- Displacement. Detrimental displacement is the removal of 1 or more inches (depth) of any surface soil horizon, usually the A horizon, from a continuous area greater than 100 square feet.

- Severely-burned Soil. Physical and biological changes to soil resulting from high-intensity burns of long duration are detrimental. This standard is used when evaluating prescribed fire. Guidelines for assessing burn intensity are contained in the Burned-Area Emergency Rehabilitation Handbook (FSH 2509.13).

- Surface Erosion. Rills, gullies, pedestals, and soil deposition are all indicators of detrimental surface erosion. Minimum amounts of ground cover necessary to keep soil loss to within tolerable limits (generally less than 1 to 2 tons per acre per year) should be established locally depending on site characteristics.

- Soil Mass Movement. Any soil mass movement caused by management activities is detrimental.

Soil Risk Evaluation Framework

Soil quality (DSD) surveys will be completed in proposed treatment units when specific unit layout and prescribed activities are determined in accordance with the project Implementation Plan (EA, Appendix B). Soil assessments in the field, and specifically where and when surveys will be completed, will be guided by the SREF framework (Tables S2 and S3.) which has been incorporated into the project's Implementation Plan. For example, if a proposed project activity occurs within an area with high soil resilience and has documented past activities, the soil risk category falls within level "C," which requires a survey of existing soil DSD prior to implementation and application of appropriate design features.

The Soil Risk Evaluation Framework is based on available data and field observation from adjacent project areas (Piquett Fuels) suggests that application of climatic water deficit as a surrogate for soil resilience is a reasonable approach for constructing a soil risk evaluation framework. A more comprehensive report on these methods, originally developed for the adjacent Piquett project area, had been adapted for this project and can be found in the project record (PF-SOILS-008).

Additionally, the project soils assessment will be based on additional Forest Plan guidance related to logging systems. The Bitterroot Forest Plan does not allow groundbased harvest on slopes steeper than 40 percent, ground-based yarding is generally restricted on slopes <35 percent. Forest Plan Soil monitoring shows that groundbased harvest results in the greatest concentrations of soil disturbance, where other treatments, such as skyline harvest and prescribed burning result in significantly less disturbance (PF-SOILS-006).

Table S2. Soil Risk Category Decision Matrix

Soil resilience (inverse of climatic water deficit)	Water deficit range	No known past activities	Past activities	Past activities with known DSD
High	371-500	A	C	E
Low	500-589	B	D	F

Soil Risk Category (SRC)	Narrative Description
A	There are no documented past management activities within these areas and relative soil resilience within this area is considered high (i.e. better than the rest of the project area). **Actions:** Proposed project activities are subject to the standard range of design features contained in Appendix B.
B	No known past activities have occurred within these areas, but soil resilience following disturbance will be more limited than in SRC A. Management activities have potential to have more prolonged impacts than in SRC A. **Actions:** Careful selection of management activities may be required to ensure long-term soil productivity and additional design features beyond those contained in Appendix B may be warranted.
C	Past management activities have been documented in these areas, but there are currently no documented instances of persisting short- or long-term soil productivity compromise from past project implementation. Relative soil resilience is considered high. **Actions:** Inventory of persisting detrimental soil disturbance will be required within these project areas. Proposed project activities are subject to the standard range of design features contained in Appendix B. Should persisting DSD from past management activities be found during field reconnaissance, proposed project activities may need to be modified to avoid adverse soil resource effects.
D	Past management activities have been documented in these areas, but there are currently no documented instances of persisting short- or long-term soil productivity compromise from past project implementation, but likelihood of persistence is higher than under SRC C. Relative soil resilience is limited. **Actions:** Careful selection of management activities may be required to ensure long-term soil productivity and additional design features may be warranted. Should persisting DSD from past management activities be found during field reconnaissance, proposed project activities may need to be modified to avoid adverse soil resource effects.
E	Past management activities in these areas has created persisting long-term detrimental soil disturbance. More information is needed to discern the extent to which natural site potential versus differences in past harvest practices may have influenced persisting concerns in these areas. **Actions:** Careful selection of management activities may be required to ensure long-term soil productivity and additional design features may be warranted. Proposed project activities may need to be modified to avoid adverse soil resource effects.
F	Past management activities in these areas has created persisting long-term detrimental soil disturbance. Management activities may have more prolonged impacts than in SRCs A, C, and E. **Actions:** Careful selection of management activities is required to ensure long-term soil productivity and additional design features may be warranted. Avoidance of commercial harvest or prescribed burning in these areas should be considered as well as exploration of potential restoration opportunities. If project activities are deemed necessary and/or appropriate, additional design features may be necessary.

Field Measurement Methodology for Soil Quality

The proposed treatment units identified for field review within the SREF framework will utilize detrimental soil disturbance walkthrough surveys and traverses following the Forest Soil Disturbance Monitoring Protocol. Units will be surveyed based on the Soil Risk Category (SRC) guidance outlined in Table S3.

Table S3. Soil Risk Category Survey Guidance

Soil Risk Category (SRC)	Pre-Implementation Practices
A,B	Actions: Proposed project activities are subject to the standard range of design features contained in Appendix B. *Pre-project DSD or CWD soil surveys in units are only needed if the layout crew or other resource special survey identifies: • past disturbance (such as excavated skid trails, tree stumps or persistent fire consumed CWD, high severity fire effects) covers greater than 15% of the unit; and/or • recent (< 10 years) high severity fire covers greater than 15% of the unit; and/or • lack of CWD.
C, D	Actions: Soil inventory of persisting detrimental soil disturbance may be required within these project areas. Proposed project activities are subject to the standard range of design features contained in Appendix B. Should persisting DSD from past management activities be found during field reconnaissance, proposed project activities may need to be modified to avoid adverse soil resource effects. Pre-project DSD and CWD soil surveys are needed once unit boundaries are established if the following proposed treatments/conditions are met: • ground-based yarding is proposed on slopes < 40%; or • mechanized clipping is proposed on slopes >40%; and/or • temporary road construction. Combined with: • past vegetation management that has occurred within the last 35 years; and/or • recent (< 10 years) high severity fire covers greater than 15% of the unit; and/or • lack of CWD. *If the layout crew or other resource specialist survey does not identify lack of CWD and/or evidence of past management (such as excavated skid trails, tree stumps or persistent fire consumed CWD, high severity fire effects), no soil inventory in units is needed.
E, F	Actions: Soil inventory of persisting detrimental soil disturbance will be required within these project areas. Avoidance of commercial harvest or prescribed burning in these areas may also be considered as well as exploration of potential restoration opportunities. Design features in addition to the standard range of design features contained in Appendix B may be warranted. Pre-project DSD and CWD soil surveys are needed once unit boundaries are established if the following treatments are proposed: • ground-based yarding on slopes < 40%; or • mechanized clipping on slopes >40% is proposed; or • unit-wide prescribed fire operations; and/or • temporary road construction.. Should pre-project soil inventory identify units approaching 15% DSD and/or CWD limitations, soil mitigations and/or a soil restoration plan will be developed and implemented with proposed vegetation/fuels treatments to ensure long-term soil productivity is maintained.

These surveys could identify past management activities such as timber harvest that still result in DSD. Upon survey conclusions the adaptive management strategy outlined in the Implementation Plan could yield changes to proposed management actions to protect soil resources. Soil surveys will follow guidance provided in the documents listed below. These documents can be found in PF-SOILS-003.

- The Region 1 Approach to Soils NEPA Analysis Regarding Detrimental Soil Disturbance In Forested Areas – A Technical Guide, March 2009
- Forest Soil Disturbance Monitoring Protocol, Volume 1 Rapid Assessment. USDA Forest Service. Gen. Tech. Report WO-82A. September 2009
- Soil –Disturbance Field Guide. USDA Forest Service. National Technology & Development Program. 0819 1815-SDTDC. August 2009.

Resource Indicator: Soil Organic Matter (CWD)

Soil organic matter management utilizes coarse wood recommendations from the *Coarse Woody Debris (CWD) Recommendations for the Bitterroot National Forest* (PF-SOILS-007), which tiers to Forest Plan direction. This document provides an updated understanding of ecological dynamics related to coarse wood and provides site-specific guidance based on habitat type and soil type. Upon completion of commercial harvest and prescribed fire activities, the levels of coarse woody material (greater than 3 inches diameter) have been established (see Table S3). This material encompasses both standing dead as well as down woody fuels.

Table S4. Coarse Woody Debris requirements by Fire Group

Fire Group	Coarse Woody Debris (CWD) (Tons/acre)
Warm, Dry Ponderosa Pine and Douglas-fir (FG-2 & 4)	5-10
Cool, Dry or Moist Douglas-fir (FG-5, 6)	10-20
Cool Sites Usually Dominated by Lodgepole Pine (FG-7) Dry, Lower Subalpine (FG-7) Moist, Lower Subalpine (FG-9)	8-24

Field Measurement Methodology (CWD)

The proposed treatment units will adhere to the requirements in Table S4. Subsequent monitoring will include walkthrough surveys, traverses and photo points. Should units fall outside of these ranges and yield CWD which is less than desirable, the adaptive management strategy outlined in the implementation plan could yield changes to proposed management actions such as the retention of more standing trees for future CWD recruitment or a determined amount of slash left on-site. CWD soil surveys followed guidance provided in the document listed below. This document can be found in PF-SOILS-009.

- The Photoload Sampling Technique: Estimating Surface Fuel Loadings From Downward-Looking Photographs of Synthetic Fuelbeds. USDA Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-190. April 2007.

Affected Environment

Humans and natural events have influenced the landscape of the Mud Creek drainage through wildland fire, flood events, timber harvest, road building, and human induced fire and fire suppression. These actions have influenced soil conditions throughout the Mud Creek planning area.

Spatial and Temporal Context for Effects Analysis

The Region 1 Supplement 2500-2014-1 (PF-SOILS-002) defines an activity area as the land area affected by a management activity to which soil quality standards are applied. Examples include timber harvest units, landings and temporary roads; mechanized fuel treatment units; and prescribed burn units. Activities outside of the locations of proposed management are not subject to a cumulative effects analysis because they do not overlap spatially with the lands being proposed for management in the Mud Creek project area. Loss of soil quality in a treatment unit will not lead to a loss of soil quality in an adjacent stand or other areas in the watershed. The analysis for cumulative effects are the same that are used for the existing and direct/indirect effects analysis. Assessment of cumulative effects on soil quality and organic matter at scales larger than the specific treatment unit boundary (such as the watershed scale) misrepresents the effects of management activities by diluting the site-specific effects across a larger area. As such, this analysis will apply the 15% DSD soil resource indicator at the same scale as it is traditionally used under “unit-based” NEPA analyses. Typical units sizes range from 10 to 40 acres.

System roads and associated permanent log landings will not be analyzed in terms of soil quality as these areas will remain in a compacted state to facilitate long-term use in relation to management activities. Road-related erosion and sediment yield will be analyzed in the Aquatic Resources analysis and as such will not been further analyzed in this report.

With respect to temporal bounds, soil and vegetation recovery following low severity burning generally occurs rapidly (e.g. Neary et al 2005; Robichaud et al. 2010). Silvicultural prescriptions for this project work are designed with the intent of stand re-entry in approximately 30-35 years. Accordingly, this analysis addresses the potential effects of this project on soil productivity through that same time frame.

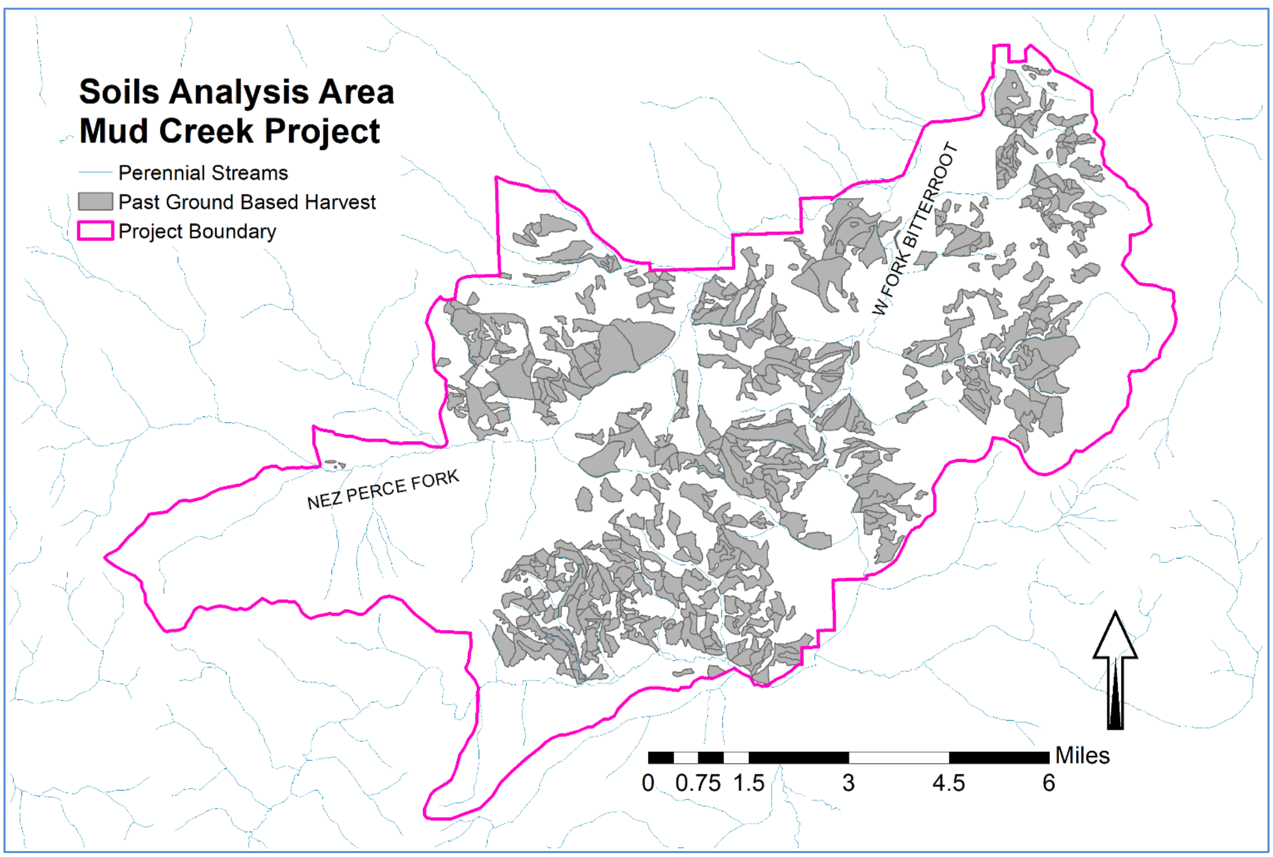

Figure S1. Analysis area for soil resources in the Mud Creek Project Area.

Existing Condition

Geologic and Geomorphic Context

Approximately 86% of the Mud Creek project area is underlain by granite, metamorphosed variants (monzogranite/granodiorite) with the remaining being of volcanic origin. These parent materials often produce coarse-textured, well-drained soils with high coarse fragment contents, though soils mapped in monzogranite in some cases are clay-enriched. Approximately four percent of the project area is comprised of felsic intrusive rock underlying alluvium within the Nez Perce Fork and West Fork Bitterroot River valley bottoms.

All of the soils in the nearly 48486 acre project area have been mapped as complexes within multiple unique landtypes (the Bitterroot N.F. has a landtype-based soil survey that accounts for geomorphology in tandem with soil properties). Approximately one third of the project area is comprised of ten landtypes spanning dissected mountain slopes (steeper transition areas from ridgetops to the valley bottoms). Erosion potential generally is higher in areas with steeper dissected slopes and on granular soils. Soils within these families generally display poor development and are often shallow, particularly on south aspects.

The erosion rate depends on factors such as geologic parent material, soil type, slope, soil placement, vegetation, and human activity. Erosion potential also increases when vegetation is removed, and soils are compacted. Some map units in the project possess volcanic rock parent material which is composed of more coarse rock and is generally less sensitive than the more erosive granitic landtypes and yield well drained soils.

Previous Land Management

The Mud Creek project area has a long history of active management. The Forest Service Activity Tracking System (FACTS) database includes commercial harvest activities dating to the 1960's in the project area. Approximately 14577 acres of vegetation management activities have been documented within the project area, with some units having received multiple treatments through the years. Just under one third of the managed acres documented in FACTS were treated with silvicultural prescriptions that removed the majority of standing timber (stand clearcut/shelterwood removal cut/seed tree cut). Much of this work was completed via ground-based harvest systems in the mid 1960's and mid 1980's. The most recent harvest activities occurred in 1995.

A large percentage of units clearcut in the 1960's were converted to terrace plantations. Several terraces were evaluated within the Mud Creek project area. When constructed, benches were cut exposing bare mineral soil- often devoid of or having limited organic enrichment - and pushing the surface organic-enriched soils off the flat bench to the riser slope between terrace benches.

Today, terraces in this area display a range of soil conditions. Some terrace benches support diverse understory vegetation assemblages resembling those seen in undisturbed adjacent stands. Organic litter and duff has accumulated on site. Soils across these sites display limited to no compaction, intact soil aggregates, abundant fine root expression, and the beginnings of organic enrichment at and near the soil surface.

In contrast to these sites, some areas, particularly south aspects with shallow depths to bedrock, display virtually no understory revegetation (invasive plant species can be a concern), only a thick (on the order of half an inch to an inch) bed of ponderosa pine needles. Soils are still compacted in these areas and display little to no organic matter recovery. Soils on sites such as these may be classified as high risk should water deficits be high.

No past prescribed burning has been documented within the Mud Creek project area in the FACTS database.

Past Wildfire Activity

Just over 8639 acres of recorded wildfire (included areas that have re-burned) have been documented within the Mud Creek project area. Nearly 3353 acres of the project area was burned or re-burned by wildfires prior to

1940. The remaining 4920 acres was burned during the fires of 2000, the Rombo fire in 2007, and the Bare Castle fire in 2005. Soil burn severity in wildfires is variable based on the fuel loading conditions of the burned environment, resulting in a mosaic of burned conditions across the Mud Creek project area.

Based on observations in the Mud Creek project area and field assessment within the nearby Piquett Fuels project area, evidence of past fire impacts to soil physical properties were not observed. Since fire effects typically are transient, with most within the first few years, the largest lasting effects may be the reduced amount of forest floor organics and coarse wood. Soil condition as it relates to wildfire and coarse wood will be evaluated during individual project development within the broader Mud Creek project area.

Existing Soil Quality (DSD) – Mud Creek Project Area

Approximately 800 acres were monitored for detrimental soil disturbance conditions within the Mud Creek project area. Although these surveys were not directly correlated with future unit boundaries, they laid the framework and provided validation for the SREF classification specific to the Mud Creek project area. Surveys were primarily focused within areas identified as Soil Risk Category C or D based on the SREF classification system. DSD in these surveyed areas ranged from 0% to 16% DSD with most units showing little to no existing disturbance; signs of past disturbance included pockets of understory plants with less diversity and abundance than corresponding undisturbed areas, limited organic matter recovery, and rutting. These areas were generally small and isolated and, as noted above, not deemed detrimental in every instance. Persistent disturbance is attributable to past ground-based yarding.

To better discern what edaphic, physiographic, climatic, and/or management-specific controls may be influencing persistence of detrimental soil disturbance, further analysis was undertaken. Monitored units were overlaid with bedrock geology and soils map units and visually evaluated in ArcGIS to look for correlation. Harvest activity, harvest method, and years since past harvest were reviewed concurrently. Summary statistics were computed for gridded climatic water deficit data using monitored units as zonal boundaries. A soil productivity risk map was developed from these variables and linked to the 6 distinct Soil Risk Categories (SRCs) outlined in the SREF process. This spatial representation of the SREF will help guide Implementation and Monitoring (Figure S2).

Existing Soil Organic Matter (CWD) – Mud Creek Project Area

The current amount of coarse wood greater than 3 inches has been evaluated in scattered portions of the project area on approximately 250 acres. Conditions range from the desired stocking levels by fire group listed above, to those lacking adequate amounts of woody debris. Although these site-specific areas where existing conditions have been evaluated represent a small portion of the project area, the initial investigation gives inference to the range of conditions that currently exist on the landscape.

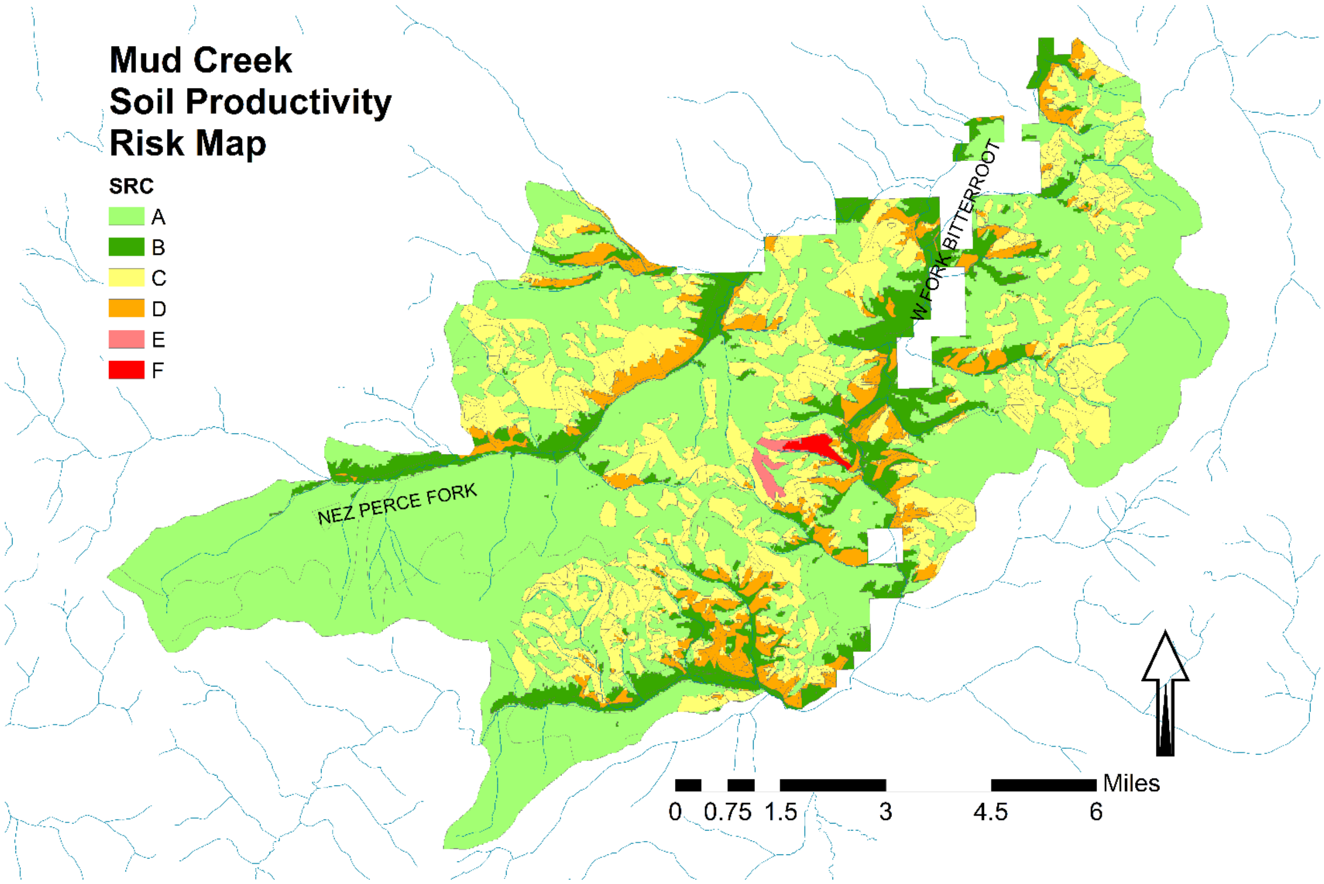

Figure S2. Soil Productivity Risk in the Mud Creek Project Area.

Environmental Consequences

Effects are discussed in the context of current research and take into consideration the project assessment indicators for issues related to soils. The effects on soils are discussed as changes over time on the two soil resource indicators; Soil Quality (DSD) and Soil Organic Matter (CWD). The first of which includes soil erosion and soil disturbance (detrimental compaction, displacement, puddling, and severe fire) and the latter which represents soil organic matter, groundcover, coarse woody material and nutrient cycling. Potential effects of the treatment activities are discussed considering all management requirements, and best management practices; analysis processes are documented for the adjacent Piquette Creek project, which has similar planned activities in PF-SOILS-008. Cumulative effects are assessed for the soils areas that are potentially most affected by the proposed actions.

Direct, Indirect, and Cumulative Effects of the No-Action Alternative

The No Action Alternative would not lead to direct detrimental soil disturbances in the project area. The No Action Alternative maintains the existing condition of the project area and provides a base line to evaluate the effects of the action alternatives.

Soil Quality (DSD)

<u>Soil Erosion, Soil Disturbance</u>

The No-Action Alternative (Alternative 1) would sustain existing conditions and the natural watershed responses to past disturbances and recent wildfire. Existing conditions would moderate over time as previously harvested units and wildland fire areas recover. There would be no new temporary or permanent road construction in the Project Area and the associated acreage would not be disturbed from these road building activities.

The No Action Alternative would not alter the current soil erosion and mass wasting regimes in the project area. Natural and human caused wildfires will likely continue to affect the project area and cause consumption of the protective layer of litter and duff on the soil surface (background information on the 2000 fires and erosion are provided in PF-SOILS-005).The occurrence of substantial levels of soil erosion and mass movements on the forest has been low where low severity fire has occurred (based on monitoring conducted on the forest over the last 20 years). Larger fires and those with moderate or high severity may result in soil erosion and mass movement depending on ground conditions and storm activity (Parrett et al. 2003). Soil erosion occurs where ground cover, duff, and litter are consumed, or hydrophobic soil conditions develop. Mass movement occurs primarily in the form of debris torrents within channels following high severity, short duration storm events (Background information on debris torrents provided in PF-SOILS-005). Indicators of slope instability were not identified during field surveys. Although roughly 30% of the project area lies on steeper dissected slopes, the majority of gentle to moderate slope gradients reduce the potential for slope failure in the event of high severity wildfire. Loss of productive organic horizons through fire consumption and subsequent erosion would be of greater importance for soil productivity than mass wasting in the project area.

Soil Organic Matter (CWD)

Organic Matter, Groundcover, Coarse Woody Material and Nutrient Cycling

The No Action Alternative would allow all standing trees (dead and alive) over time to shed needles and fine branches that would accumulate on the soil surface. Eventually, trees would fall to the ground, providing coarse wood for decomposition into the soil. Soil organisms would slowly decompose the organic materials, adding beneficial humus to the soil. The primary source of soil organic matter is the decomposition of fine roots rather than the decomposition of surface organics (Powers, et. al., 2004). Nutrients associated with this material would slowly become available for plant growth. This process would continue until another major disturbance such as fire consumes or partially consumes the accumulated litter, duff, and woody material.

Long-term effects on soil health and productivity are likely to be relatively small from future fires that are within the historic range of variability (Brown et al. 2001). Fire severity exceeding the historic range could have detrimental effects on soil productivity and health through the oxidation and loss of soil organic matter and associated soil biota, as well as through accelerated rates of erosion (Harvey et al. 1987; Harvey et al. 1988).

Following the Fires of 2000, Brown et al. (2001) recommended "optimal levels" of 5-15 tons/acre of coarse wood for warm, dry ponderosa pine and Douglas-fir habitat types, and 10 to 25 tons/acre for cool, dry to moist Douglas-fir and for cool lodgepole pine and lower elevation subalpine fir habitat types in burned areas. Optimal levels account for the historic range of variability in fuel loadings, fire responses to these loadings and to climatic factors in the past few hundred years of the pre-settlement period, as well as considering the risks to resources and firefighters. Brown et al.'s (2001) coarse woody material recommendations agree with those of Graham et al. (1994) and Harvey et al. (1987) for unburned Rocky Mountain forests.

Microorganisms would continue to populate the soils, contributing towards site productivity through nutrient cycling and development of soil structure aggregates in areas of poorly developed mineral soils. The occurrence of severe wildfire may alter soil microbial communities by super heating mineral soils and consuming organic matter necessary for microorganism functions.

Direct and Indirect Effects of the Proposed Action

Activities associated with the proposed action have the potential to influence multiple attributes of soil quality and soil organic matter. These general effects listed provide a summary of anticipated soil impacts in relation to land management such as road building, timber harvest and prescribed burning. Currently timber harvest and prescribed fire design is done with direct collaboration with soil and watershed specialists to avoid most of the potential effects outlined below. The effects analysis below includes the implementation of soil resource design features, project monitoring requirements as outlined in the Mud Creek project design features and the Mud Creek Implementation Plan (EA Appendices A and B). Soil monitoring on the Bitterroot National Forest has shown that implementation of common design features, BMPs, and site-specific mitigations is known to limit soil disturbance effects and ensure soil quality is maintained (PF-SOILS-006).

Below, the impacts of activities anticipated in the Mud Creek area are discussed as they relate to soil quality and organic matter. These management activities have influences to physical, biologic, and nutrient cycling functions of soil. For example, timber harvest with heavy machinery may result in localized compaction, rutting, or top soil displacement (physical) and has potential to reduce nutrient availability from the removal of organic matter during harvest operations (biologic and nutrient cycling).

Soil Quality (DSD)

Soil Erosion, Soil Disturbance

Under the proposed action, direct effects on soil physical characteristics would occur only within the boundaries of the treated units. Soil quality is most affected by soil disturbances associated with the harvesting and transporting of logs. When treatments are proposed in the Mud Creek project area, they will be subject to site specific design criteria included in the project's Design Features (EA, Appendix A). The effectiveness of design features is included in the Design Features; the assumptions of BMP and design feature effectiveness is based on the Bitterroot Forest Plan Soil monitoring reports from 2002 to present (PF-SOILS-006).

Most detrimental effects would be concentrated on primary skid trails and landings, where heavy equipment may compact, displace, or rut soil, thereby reducing pore spaces and impeding root growth. The proposed treatment areas would be harvested using designated trails and landings that are laid out to spatially occupy less than 15 percent of the activity unit. To the extent feasible, trails and landings would utilize existing roads and trails, which would limit new disturbance. When mechanical operations occur under dry soil conditions or over snow and frozen ground soils are less prone to compaction and rutting. Coarse textured soils with high coarse fragment contents and ample drainage are less prone to compaction, rutting, and loss of soil structure when driven upon, making them conducive to less DSD than some other soil types. Soils with high coarse fragment contents and limited vegetation cover, however, can be more susceptible to displacement. Implementation of project design features (including, but not limited to: operating within specific soil moisture conditions, adhering to prescribed season of operation, operating exclusively on designated trails and landings) would minimize risk of extensive topsoil displacement.

Prescribed burning can have mixed effects since much of the area in departed conditions from what is considered natural fuel loading. The impacts from timber harvest accompanied by heavy slash burning can deplete soil organic matter and result in localized top-soil displacement and erosion. Soil erosion can occur when the surface soil is compacted or when the loose surface soil and its protective layer of organic material are changed by management activities such as prescribed burning. Loss of topsoil from erosion can adversely affect soil productivity by reducing water holding capacity, soil organic matter, nutrients, biota, and depth of soil. Generally, prescribed burning activities on the Bitterroot National Forest do not result in detrimental soil disturbance (USDA Forest Service 2019).

Reeves and others (2011) collected, collated, and statistically analyzed current and legacy soil monitoring data from 11 National Forests in the Forest Service's Northern Region. Mean detrimental soil disturbance for ground-based harvest on the Bitterroot National Forest was found to be 7.4%. Note that only nine units were analyzed for this study. The one skyline harvest evaluated in the publication was found to have approximately 2% DSD.

The 2018 Bitterroot N.F. Biennial Monitoring Evaluation Report contains a recent compendium of past soils monitoring across the forest (USDA Forest Service 2019, PF-SOILS-006). Analysis conveyed within the report shows that harvest activities have displayed consistent downward trends in DSD since the 1990s and over the past five years per-harvest unit DSD has generally fallen below 10%, with minor exception. DSD associated with skyline harvest has been observed to be 4% or less over the past eight years.

It is explicitly noted within the report that ground-based skidding on slopes at or near 40% gradient pose the greatest concern due to potential for topsoil displacement. This concern would be addressed with implementation of the design feature limiting operations on gradients greater than 35%.

Roads are considered an administrative use and are not considered for soil quality; however mass failures and erosion events originating from roads are soil disturbance. Road instability and mass failure potential will be analyzed during project implementation (EA, Appendix B).

Site recovery would be expedited through reclamation of the temporary road and skid trails. These activities may include seeding with native plants and soil aeration/ripping. Dick et al. (1988) found that subsoiling (tilling) restored biological processes that were reduced by soil compaction. In general, tilling or scarifying a compacted soil improves productivity by reducing the resistance of soil to root penetration, and providing improved soil drainage and aeration to enhance seedling establishment and tree growth (Bulmer 1998) and improve the environment for soil organisms. Of note is that the goal of soil restoration is to set the stage for the soil to begin the recovery process; soil restoration is not an immediate result of ripping, planting, or any other activity.

Through application of the Soil Risk Evaluation Framework (SREF), tools for achieving desired conditions would be informed by site-specific soil resilience, thereby minimizing recovery duration.

Soil Organic Matter (CWD)

Organic Matter, Groundcover, Coarse Woody Material and Nutrient Cycling

The proposed action is designed to leave a variety of organic matter on the site. The practice of leaving organic matter on site provides for microbial populations which help maintain site productivity (Harvey et al. 1994). Vegetation and organic matter protect the soil surface from raindrop impact, dissipates energy of overland flow, binds soil particles together, and dampens soil temperature extremes and daily fluxes. Studies have found that 60 percent effective ground cover reduced sediment movement substantially and 30 percent ground cover reduced erosion by half compared to bare soil (Robichaud et al. 2000). Logging slash will add to effective ground cover until fine logging slash decomposes over several decades (Clayton 1981).

Any increase in groundcover and/or fine logging slash through harvest may be offset by fuel treatments. Fuel treatments may reduce the amount of organic matter and groundcover in the short-term (0-5 years after treatment) using prescribe fire. In the long-term (greater than 5 years), re-growth of vegetation and annual needle drop would provide groundcover and leaf and litter material necessary for soil organic matter development.

Forest floor displacement moves the forest floor and top soil from one place to another. In the absence of fire or erosion when displacement events can be exacerbated by the loss of vegetative cover, the displaced material is not lost from the site. Page-Dumroese et al. (2000) reports that productivity losses from forest floor displacement (while initially high in localized areas less than 100 square feet) may not be significant to site sustainability when compared to large-scale losses from fire or erosion. Powers et al. (2004) noted that complete organic matter removal on long-term soil monitoring plots across the nation had no impact on total vegetative production after 10 years.

All harvest prescriptions would leave a portion of the existing coarse woody debris on the site. Yarding will be either whole tree with conventional yarding or in woods processing with a forwarder system. Coarse woody debris (material greater than 3 inches in diameter) will be left from designated leave trees, both standing and down, and from breakage of limbs and broken tops that will occur during harvest. Coarse wood is defined as material greater than 3 inches in diameter. Larger coarse wood (greater than 15 inches in diameter) is preferred for soil productivity. Large coarse wood persists for longer durations and provides greater benefits to soil development than smaller coarse wood. Large coarse wood is also much less of a concern for fire management. Following the treatments, the stands will be capable of producing large coarse wood at a faster rate for soil development than current conditions. To the extent feasible, the largest coarse wood (snags or logs) will be left on-site to satisfy coarse woody material requirements for each treatment unit. Silvicultural prescriptions will account for additional trees that will be required for future coarse wood recruitment in the thinned stands. The amounts of coarse wood listed in Table S4 for each Fire Group will maintain future soil productivity. Additional information concerning coarse woody material is outlined in PF-SOILS-007.

The proposed commercial and non-commercial thinning treatments are anticipated to leave slash on the ground through the winter and into late summer/fall before prescribed burning will be completed. This will provide opportunity for the nutrients in the slash to be leached into the soil.

Nearly all areas proposed for thinning in the Proposed Action will include whole tree yarding or leaving tops attached. Regarding effects of whole tree harvesting on the growth of trees, Wells and Jorgensen (1979) believe that as long as rotations are long, the depletion of the major nutrients needed by plants should not be excessive in relation to total reserves in the soil and that the reserves would be replenished between cuttings. However, they also recognize that plant growth is dependent on the amount of nutrients actually available to the plants and that this available pool of nutrients can become in short supply in some circumstances.

Wells and Jorgensen (1979) reviewed literature about nutrient pools and cycling in forest ecosystems. Their publication indicates that most of the total nutrient content occurs in the mineral soil. The majority of stands examined had 8 to 10 times as much nitrogen in the soil reserves as in the trees. Nitrogen is typically the most limiting plant nutrient in forested ecosystems. The major source of nitrogen replenishment to the soil reserves is through mineralization of organic matter, atmospheric inputs, and nitrogen fixation by soil organisms. Jorgensen et al (1980) concluded there would be no long-term depletion of nitrogen reserves because lost nitrogen would be more than replenished by inputs from precipitation and by biological nitrogen fixation over a rotation of 100 to 150 years.

Phosphorus is a nutrient (macronutrient) critical for plant growth and is often only slowly available to plants. Its main sources are the weathering of soil minerals such as apatite and through organic matter decomposition. The phosphorus removal rate through timber harvest is usually less than it is for nitrogen because an even larger proportion of total site phosphorus occurs in the soil than in above ground biomass. Morrison and Foster (1979) site the disparity in nutrient distribution between above and below ground biomass in a *Pinus banksiana* forest growing in sandy glacio-fluvial soil in Ontario. The percentage of total site nitrogen was 95 percent in the soil reserves and 5 percent in the tree canopy; for phosphorus 99 percent of total site phosphorus occurred in the soil whereas only 1 percent was found in the tree canopy.

The status of other nutrients is unknown although there are no site indicators which would point to a problem with nutrient availability or cycling in the units. Removal of potassium in whole tree harvests is modest in comparison to soil reserves according to Wells and Jorgensen (1979). Tree growth and ground cover is within the range expected for the site conditions.

Page-Dumroese (2000) found that relatively small levels of disturbance (less than 15 percent of the area) resulted in relatively small losses in carbon, nitrogen, and cation exchange capacity (CEC), ranging between 1 to 13 percent of the available pools. She concludes that at these levels of loss, current soil quality standards appear to be adequate. It must be noted that this is based on initial research from the Long-term Site Productivity Project (LTSP) and results may change as more data is accumulated in future years.

Fire suppression in Ponderosa pine has resulted in a build-up of forest litter and accumulation of organic matter (DeLuca, 2000). DeLuca's research has shown the positive benefits of reducing fuel loading and renewing the growth of desirable understory plants through the use of fire or harvest or a combination of both. Ponderosa pine communities commonly accumulate little inorganic nitrogen in mineral soil because of the slow decay rates and rapid uptake by plants and microorganisms. In addition, limited quantities of nitrogen may be available due to the accumulation of organic matter composed of woody residue, naturally low in nitrogen. Wildfire and prescribed fire release plant available nitrogen, however, a first entry of high severity wildfire may result in root kill and overall reduction in nitrogen mineralization potential.

DeLuca (2000) found prescribed fire following a selection or shelterwood harvest to have a short-term increase in mineral nitrogen followed by a long-term decline in available nitrogen. This may seem like a negative impact of fire reintroduction; however, the reduced stand density has a lower nitrogen demand. In addition, the Nitrogen: Potassium ratio would be in better balance increasing the trees resistance to disease and insects. Retaining limbs and branches on site over the winter provides for nutrient leaching into the soil (Palviainen et al. 2004).

To summarize, by maintaining organic matter and ground cover on at least 85 percent of the site, as prescribed in the proposed action, nutrient cycling and availability will not be altered. The design features and Region 1 soil quality standards are prescribed to achieve this desired outcome. Localized losses may occur at landings or where severe fire occurs.

Cumulative Effects Overview

Cumulative effects are the result of all the impacts past, current, and reasonably foreseeable activities have on a resource. Past activities have resulted in the "Existing Condition" described above. The anticipated effects from proposed activities were then added to the existing condition and described in the section titled "Environmental Consequences." The sum of the existing condition and the direct and indirect effects of proposed actions in combination with current and reasonably foreseeable actions result in the cumulative effects described in this section. The analysis areas for evaluating the cumulative effects with regard to water resources consist of the same watersheds identified earlier in the document.

Soil resources would be protected under the implementation of the Proposed Action. This is based on past monitoring of soil conditions such as detrimental soil disturbance and coarse woody debris across the Bitterroot National Forest, implementation and the effectiveness of project related BMPs, adherence to the implementation plan within the condition based framework (See Implementation Plan); and all laws, regulations, and policies being met. Below is the rationale for this conclusion.

Past Actions and Their Effects on Current Conditions

Legacy soil disturbance (disturbance that occurred as a result of past activities) forms the foundation of the soil conditions on the landscape today, the existing soil condition. These activities include but are not limited to timber harvest, grazing, road construction, recreation, restoration, and fires.

For past, present, or future activities to overlap in time, the effects on soils from the activities must overlap. Soil physical changes (detrimental compaction, detrimental displacement, detrimental erosion, severe burning, and puddling) can persist in the landscape for greater than 20-40 years following management activities. Biological soil conditions change quicker, for example re-vegetation occurs within 5 years (under most situations) and organic matter begins to rebuild in 10 years but may take greater than 50 years to reform humus. Time discussions will look back to at least the 1970's, which cover both the physical and biological aspects of the soil.

Ongoing and Reasonably Foreseeable Activities

Other than continued non-motorized recreation activities, there are no on-going or reasonably foreseeable activities overlaying any of the proposed units in the action alternatives that would affect soil resources. Fires are always a possibility and may overlap the proposed units.

Cumulative Effects – Proposed Action

Soil Quality (DSD)

Harvest activities that have created long term (>60 years) DSD are primarily the result of past ground-based yarding. Yarding practices prior to the late 1980's often did not adhere to soil protection measures such as operating on dry soils or designated skid trails. Timber was removed from the forest as economically as possible. Logging systems from the 1960s constructed terraces, a feature that was known to promote fast and efficient tree growth and harvesting systems, but left several sites in the project area with long-term disturbances. These soils were compacted, displaced by skidding, and had significant top-soil/subsoil mixing which stunts long-term soil development. While many of these areas are recovering, some terraces on low soil resilient sites (south facing, dry) were not showing signs of long-term recovery.

Based on existing field surveys in and around the project area, most soils in previously disturbed areas that were implemented during this time frame are recovering. Previously displaced areas have redeveloped organic horizons and are developing productive topsoil horizons in most areas. More site-specific conditions that are directly connected to planned units within this project will be assessed prior to implementation. Should these more current planned surveys present less than desirable conditions, management options will be adjusted to protect the soil resources within the Forest Plan Standards and Guidelines.

Some areas, such as previously used landings, burn piles, and major skid trails, have minimal organic surface development and mineral soils are vulnerable to erosion or weed colonization. Compaction has longer lasting effects on soil types with fine textures, especially clay loam soils. There are minimal clay loam textured soils present in the project area, and coarse textured sandy soils are common. This inherent geology lends the project area to less compaction from future entries. Natural recovery of subsurface compaction will continue over time through freeze/thaw cycles and root penetration.

During project implementation, a soil scientist will review the desired treatment activities and effectiveness of design criteria at the unit level (EA, Appendix B). Because of the effectiveness of design features to minimize DSD, it is anticipated that proposed activities will not result in cumulative DSD above the 15% R1 soil quality threshold. The proposed activities will add to cumulative soil effects in the project area; however, all treatment units will have 15 percent cumulative DSD or less after treatment and will meet Region 1 soil quality standards. Previous Forest Plan Monitoring shows that DSD in the project area has been limited to less than 15% when standard design features, such as operating on dry soils and limiting harvest to less than 35% slope are used (PF-SOIL-006).

Soil Organic Matter (CWD)

The CWD requirements for this project are based on the most current science, which differs from the amounts shown in the Forest Plan. A forest plan amendment has been developed to address the CWD issue. Since the 1987 Forest Plan, forest plan amendments have been made to adjust CWD levels. Project amendments were needed to ensure CWD retention in fuel reduction treatments were based on current science. The modifications of the CWD requirements for this project will not have appreciable cumulative effects at the site or forest scale.

Cumulatively, by implementing this site-specific standard for CWD and snags, the area is expected to have appropriate levels of CWD by fire group over time, fully supporting Forest Plan goals and objectives. In fuel reduction project areas where CWD is nearing the low threshold levels, care will be taken to not intentionally ignite CWD during hand lighting operations. Prescribe fire can be used in these areas to recruit additional CWD through burn mortality. Burning prescriptions will be carefully written and implemented to take these as well as other resource limitations into consideration. These treatments would not create DSD and would meet the Region 1 soil quality standards for the proposed action.

Bacteria (Nitrosomas bacteria) and fungi are relatively sensitive to the increased soil temperatures encountered with light to moderate severity fire whereas sulfur, soil structure, soil wettability, nitrogen, and organic matter are only moderately sensitive (DeBano et al. 1990). The risks to soil organisms lowers when soil moisture content is low (less than 15 percent) and the duration of the heat is less than 30 minutes. Conversely, the potential for nitrogen loss and infiltration loss increases in dry soils.

Upon completion of maintenance burning or other prescribed fire activities, at least 70 percent ground cover is necessary to prevent detrimental accelerated erosion and loss in soil productivity. Mitigation for this project will assure that in those cases where ground cover is less than 70 percent prior to burning, consumption and loss of ground cover should not exceed 15 percent. Ground cover includes duff, organic soil horizons, basal area of vegetation, fine woody material, coarse woody material, and surface coarse fragments. Prescribe fire prescriptions will be designed to meet these soil protection requirements (see Fire and Fuels report, PF-FIRE-001).

Vegetation, organic matter, and ground cover will be preserved on all but the landings and heavily used skid trails. Soil disturbance will be limited to the extent feasible through implementation of BMPs, SWCPs, and mitigations. This project will not result in irreversible changes to soil structure or organic matter over time.

Consistency with Forest Plan and Regulatory Framework

Bitterroot National Forest Plan (1987)

Under implementation of the Proposed Action, long-term soil quality and/or productivity is not expected to be compromised. Through adherence to the implementation plan, implementation of all design features, applicable BMPs, and standard timber sale contract provisions, soil resources would maintain soil productivity, thereby keeping project work in line with Forest Plan Goals, objectives, and standards.

Forest and Rangeland Renewable Resources Planning Act of 1974 (16 U.S.C. 1600-1614) (as amended by National Forest Management Act (NFMA) of 1976 (16 U.S.C. 472a)

The Forest and Rangeland Renewable Resources Planning Act states that development and administration of the renewable resources of the National Forest System are to be governed by those concepts outlined within the Multiple-Use Sustained Yield Act of 1960. Through this mandate, the act requires maintenance of land productivity as well as conservation and/or restoration where appropriate. Specific excerpts pertinent to soil resources include:

Section 2 (16 USC 1600). Under general findings, the law states that “(3) to serve the national interest, the renewable resource program must be based on a comprehensive assessment of present and anticipated uses, demand for, and supply of renewable resources from the Nation's public and private forests and rangelands, through analysis of environmental and economic impacts, coordination of multiple use and sustained yield opportunities as provided in the Multiple-Use, Sustained-Yield Act of 1960 (74 Stat. 215; 16 U.S.C. 528-531), and public participation in the development of the program;”

Section 4 (16 USC 1602) directs the Secretary of Agriculture to formulate a Renewable Resource Plan. “The Program will include, but not be limited to- "(C) recognize the fundamental need to protect and where appropriate, improve the quality of soil, water, and air resources;”

Section 6 (16 USC 1604). This section directs the creation of forest and land management plans that must "(E) ensure that timber will be harvested from National Forest System lands only where-
"(i) soil, slope, or other watershed conditions will not be irreversibly damaged;"

Long-term soil quality and productivity would be maintained through adherence to the implementation plan and implementation of design features and BMPs during project implementation. Irreversible damage to soil resources is not anticipated. As such, this work would be in compliance with the Forest and Rangeland Renewable Resources Planning Act of 1974 (as amended under NFMA 1976).

Multiple Use Sustained Yield Act of 1960

Per the MUSYA of 1960, national forests are established and shall be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes (16 USC 2 (I); Sec 528). Through implementation of proposed design features and pertinent BMPs, implementation of project work would not preclude "regular periodic output of the various renewable resources of the national forests without impairment of the productivity of the land."

Forest Service Region 1 Guidelines

Regional Forest Service guidelines require that National Forest System lands be managed to prevent permanent impairment of land productivity and maintain or improve soil quality (USDA 2014). Soil quality is maintained when erosion, compaction, displacement, rutting, burning, and loss of organic matter are maintained within defined soil quality standards.

Region 1 guidelines state that detrimental soil disturbance should be limited to 15% or less of the activity area, not including system roads. If an area would exceed 15% detrimental disturbance as result of a project, then the project must include actions to mitigate cumulative impacts, so the total impact is less than 15%. If the existing condition of an activity area already exceeds 15%, then the project must result in a net improvement in soil condition. While detrimental soil disturbances are the basis for the effects analysis, not all soil disturbances have a detrimental effect on soil productivity.

As with the other regulatory authorities mentioned above, implementation of design features and applicable BMPs would ensure that project work would comply with FS Region 1 Soil Quality Guidelines.

Statement of Findings

The Proposed Action is consistent with Forest Plan standards for soil resources. Alternative 2 would be consistent with forest plan direction and would also protect the soil resources in the project area; therefore, all state and federal water quality regulations would be met. This determination is based on the lack of detrimental direct or indirect impacts from proposed Forest Service activities.

Federal Permits, Licenses, or Other Entitlements

Any required permits related to BMPs (such as for stream crossing culvert replacements and upgrades) would be obtained prior to project implementation.

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